

(12) **United States Patent**
Melanson et al.

(10) **Patent No.:** **US 9,407,991 B2**
(45) **Date of Patent:** ***Aug. 2, 2016**

(54) **SYSTEMS AND METHODS FOR USING A SPEAKER AS A MICROPHONE IN A MOBILE DEVICE**

(71) Applicant: **Cirrus Logic, Inc.**, Austin, TX (US)

(72) Inventors: **John L. Melanson**, Austin, TX (US);
Eric Swanson, Buda, TX (US)

(73) Assignee: **Cirrus Logic, Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/673,387**

(22) Filed: **Mar. 30, 2015**

(65) **Prior Publication Data**

US 2015/0208176 A1 Jul. 23, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/915,767, filed on Jun. 12, 2013, now Pat. No. 9,008,344.

(60) Provisional application No. 61/782,388, filed on Mar. 14, 2013.

(51) **Int. Cl.**
H04R 9/08 (2006.01)
H04R 3/00 (2006.01)
H04R 1/04 (2006.01)
H04W 52/02 (2009.01)
H04R 1/10 (2006.01)
H04R 3/04 (2006.01)
H04R 19/02 (2006.01)
H04R 19/04 (2006.01)
H04R 1/02 (2006.01)
H04M 1/00 (2006.01)

(52) **U.S. Cl.**
CPC **H04R 3/005** (2013.01); **H04R 1/04** (2013.01); **H04R 1/1041** (2013.01); **H04R 3/04** (2013.01); **H04R 19/02** (2013.01); **H04R 19/04** (2013.01); **H04W 52/0251** (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC H04R 2400/03; H04R 2201/03; H04R 2499/11; H04R 2499/15
USPC 381/365, 57-59, 93, 94.1, 116, 117, 381/111, 113, 120, 96, 191; 455/569.1, 455/575.1, 90.2, 553.1, 74.1, 88, 557, 573; 379/420.01, 433.02, 433.03, 379/388.01-388.06; 700/13
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,274,794 B1 9/2007 Rasmussen
7,334,735 B1 2/2008 Antebi et al.

(Continued)

FOREIGN PATENT DOCUMENTS

GB 2526727 A 12/2015

OTHER PUBLICATIONS

International Search Report and Written Opinion of the International Searching Authority, International Patent Application No. PCT/US2014/024238, mailed Sep. 3, 2014, 11 pages.

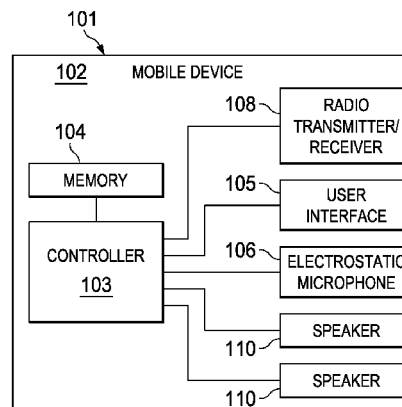
Primary Examiner — Sunita Joshi

(74) *Attorney, Agent, or Firm* — Jackson Walker L.L.P.

(57) **ABSTRACT**

In accordance with methods and systems of the present disclosure, a mobile device may include an enclosure adapted such that the enclosure is readily transported by a user of the mobile device, a speaker associated with the enclosure for generating sound, and a controller within the enclosure, communicatively coupled to the speaker. The controller may be configured to receive a signal from the speaker, the signal induced at least in part by sound incident on the speaker other than sound generated by the speaker and process the signal.

22 Claims, 3 Drawing Sheets



US 9,407,991 B2

Page 2

(52)	U.S. Cl. CPC H04W 52/0254 (2013.01); <i>H04R 2400/01</i> (2013.01); <i>H04R 2499/11</i> (2013.01)	2003/0118201 A1 *	6/2003	Leske	H04R 3/00 381/117
		2003/0202673 A1 2006/0074658 A1 *	10/2003 4/2006	Tajima et al. Chadha	G10L 17/00 704/246
(56)	References Cited U.S. PATENT DOCUMENTS	2007/0230712 A1 2010/0027817 A1 2011/0181452 A1 2013/0190041 A1 *	10/2007 2/2010 7/2011 7/2013	Belt et al. Dyer et al. Raifel et al. Andrews	H04R 3/005 455/556.1
		7,881,480 B2 8,243,961 B1 * 8,326,379 B2	2/2011 8/2012 12/2012	Buck et al. Morrill Slevin	H04M 1/6041 379/433.03
		* cited by examiner			

* cited by examiner

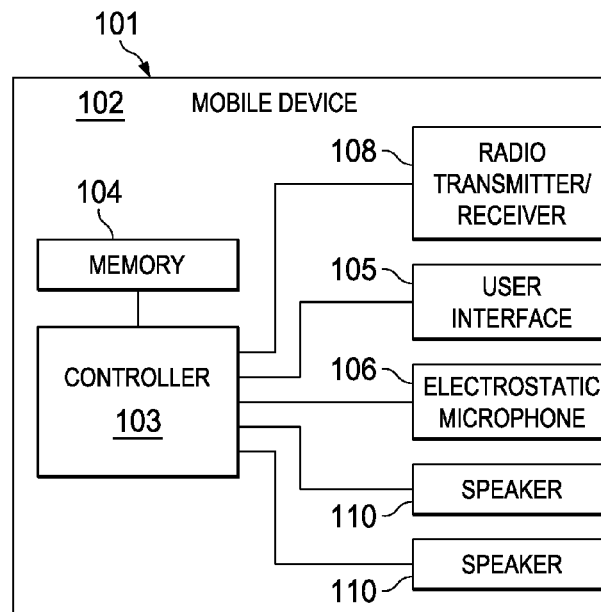


FIG. 1

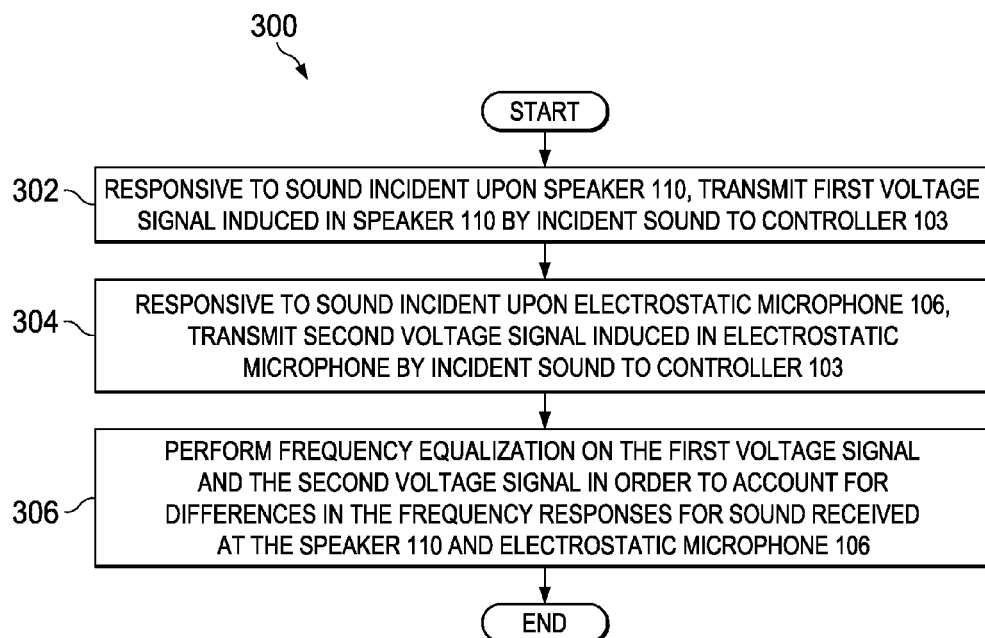


FIG. 3

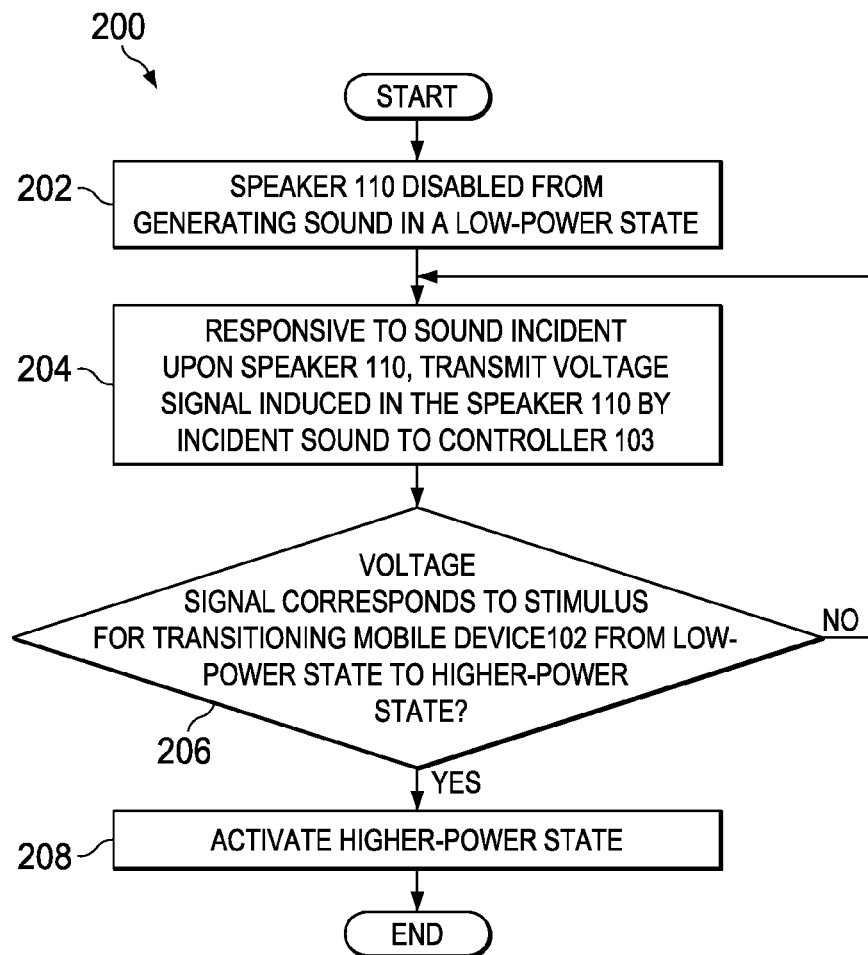


FIG. 2

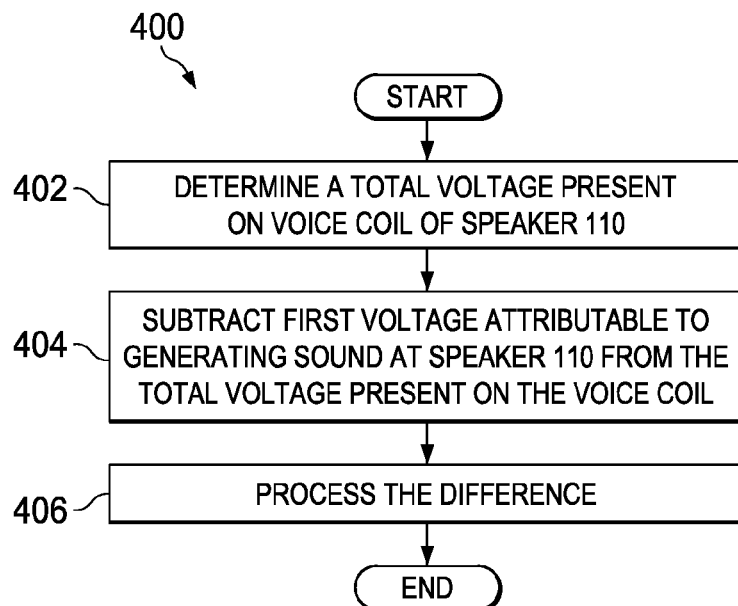


FIG. 4

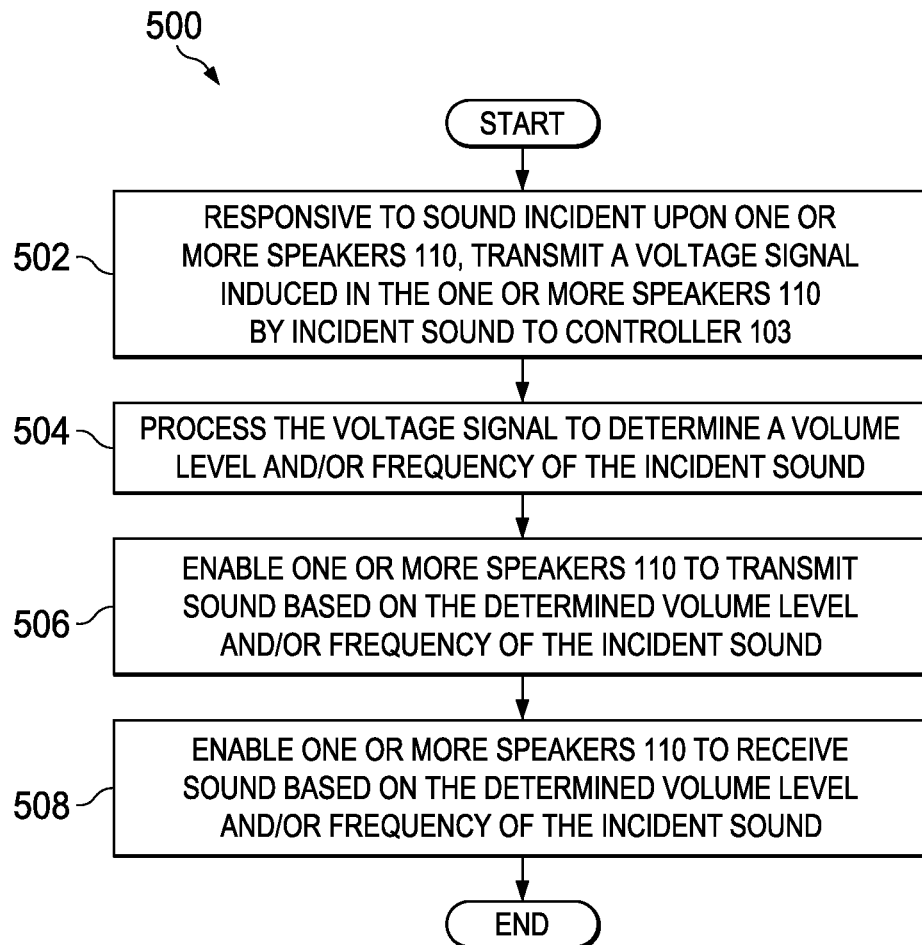


FIG. 5

1

SYSTEMS AND METHODS FOR USING A SPEAKER AS A MICROPHONE IN A MOBILE DEVICE

RELATED APPLICATION

The present disclosure claims priority to U.S. patent application Ser. No. 13/915,767, filed Jun. 12, 2013, issuing as U.S. Pat. No. 9,008,344 on Apr. 14, 2015, and U.S. Provisional Patent Application Ser. No. 61/782,388, filed Mar. 14, 2013, both of which are incorporated by reference herein in their entirety.

FIELD OF DISCLOSURE

The present disclosure relates in general to a mobile device, and more particularly, to using a speaker as a microphone in a mobile device in order to potentially improve power performance and/or audio performance of the mobile device.

BACKGROUND

Battery life in mobile devices (e.g., smart phones, tablets, handheld computers, other portable devices, etc.) is often a key design constraint. Accordingly, mobile devices are capable of being placed in a lower-power state or "sleep mode." In this low-power state, generally only minimal circuitry is active, such minimal circuitry including components necessary to sense stimulus for activating higher-power modes of operations. Typically, one of the components remaining active is one or more capacitive microphones, in order to sense for voice activation commands for activating a higher-power state. Often, these microphones consume significant amounts of power, thus reducing battery life of mobile devices.

Another shortcoming of capacitive microphones typically used in mobile devices are that they are typically suited for receiving low-volume sounds with a limited frequency range. However, it may be desirable to record loud sounds, such as a rock concert, which are above the volume range for which most capacitive microphones used in mobile devices are suited. Amplifier circuitry and bias electronics used to amplify electric signals transduced by sound received by such microphones typically draw significant amounts of power, and adapting such circuitry to increase the audio performance of microphones would likely increase power consumption and component cost. Some mobile device manufacturers have overcome this shortcoming by including two capacitive microphones: one adapted for low-volume sound, and one adapted for high-volume sound. However, such a solution may increase cost.

SUMMARY

In accordance with the teachings of the present disclosure, the disadvantages and problems associated with performance of microphones in a mobile device may be reduced or eliminated.

In accordance with embodiments of the present disclosure, a mobile device may include an enclosure adapted such that the enclosure is readily transported by a user of the mobile device, a speaker associated with the enclosure for generating sound, and a controller within the enclosure, communicatively coupled to the speaker. The controller may be configured to receive a signal from the speaker, the signal induced at

2

least in part by sound incident on the speaker other than sound generated by the speaker and process the signal.

In accordance with these and other embodiments of the present disclosure, a method may include generating, by a speaker associated with an enclosure adapted such that the enclosure is readily transported by a user of the mobile device, a signal, the signal induced at least in part by sound incident on the speaker other than sound generated by the speaker and processing the signal.

In accordance with these and other embodiments of the present disclosure, a mobile device may include an enclosure adapted such that the enclosure is readily transported by a user of the mobile device, a first speaker associated with the enclosure for generating sound, a second speaker associated with the enclosure for generating sound, and a controller within the enclosure, communicatively coupled to the speaker. The controller may be configured to receive a first signal from the first speaker, the first signal induced at least in part by sound incident on the first speaker other than sound generated by the first speaker, receive a second signal from the first speaker, the second signal induced at least in part by sound incident on the second speaker other than sound generated by the second speaker, process at least one of the first signal and the second signal to determine at least one characteristic of sound incident on the mobile device, select one of the first speaker and the second speaker as a signal source for incident sound based on at least one of the volume level and the frequency; and select the other one of the first speaker and the second speaker to generate sound based on at least one of the volume level and the frequency.

In accordance with these and other embodiments of the present disclosure, a method may include generating, by a first speaker associated with an enclosure adapted such that the enclosure is readily transported by a user of the mobile device, a first signal, the first signal induced at least in part by sound incident on the first speaker other than sound generated by the first speaker. The method may also include generating, by a second speaker associated with the enclosure, a second signal, the second signal induced at least in part by sound incident on the second speaker other than sound generated by the second speaker. The method may additionally include processing at least one of the first signal and the second signal to determine at least one characteristic of sound incident on the mobile device. The method may further include selecting one of the first speaker and the second speaker as a signal source for incident sound based on at least one of the volume level and the frequency. The method may also include selecting the other one of the first speaker and the second speaker to generate sound based on at least one of the volume level and the frequency.

Technical advantages of the present disclosure may be readily apparent to one having ordinary skill in the art from the figures, description and claims included herein. The objects and advantages of the embodiments will be realized and achieved at least by the elements, features, and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are examples and explanatory and are not restrictive of the claims set forth in this disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the present embodiments and advantages thereof may be acquired by referring to the following description taken in conjunction with the

3

accompanying drawings, in which like reference numbers indicate like features, and wherein:

FIG. 1 illustrates a block diagram of an example mobile device, in accordance with embodiments of the present disclosure;

FIG. 2 illustrates a flow chart of an example method for using a speaker as a microphone in order to detect audio stimulus for waking a mobile device from a low-power state, in accordance with embodiments of the present disclosure;

FIG. 3 illustrates a flow chart of an example method for using a speaker as a microphone at higher volume levels not suitable for reception by a capacitive microphone, in accordance with embodiments of the present disclosure;

FIG. 4 illustrates a flow chart of an example method for simultaneously using a speaker as a speaker and a microphone such that the speaker may simultaneously emit sound while capturing sound, in accordance with embodiments of the present disclosure; and

FIG. 5 illustrates a flow chart of an example method for selectively enabling speakers for transmitting sound or receiving sound, in accordance with embodiments of the present disclosure.

DETAILED DESCRIPTION

FIG. 1 illustrates a block diagram of an example mobile device **102**, in accordance with embodiments of the present disclosure. As shown in FIG. 1, mobile device **102** comprises an enclosure **101**, a controller **103**, a memory **104**, a user interface **105**, a microphone **106**, a radio transmitter/receiver **108**, and one or more speakers **110**.

Enclosure **101** comprises any suitable housing, casing, or other enclosure for housing the various components of mobile device **102**. Enclosure **101** may be constructed from plastic, metal, and/or any other suitable materials. In addition, enclosure **101** may be adapted (e.g., sized and shaped) such that mobile device **102** is readily transported on a person of a user of mobile device **102**. Accordingly, mobile device **102** includes but is not limited to a smart phone, a tablet computing device, a handheld computing device, a personal digital assistant, a notebook computer, or any other device that may be readily transported on a person of a user of mobile device **102**.

Controller **103** is housed within enclosure **101** and includes any system, device, or apparatus configured to interpret and/or execute program instructions and/or process data, and may include, without limitation a microprocessor, microcontroller, digital signal processor (DSP), application specific integrated circuit (ASIC), or any other digital or analog circuitry configured to interpret and/or execute program instructions and/or process data. In some embodiments, controller **103** interprets and/or executes program instructions and/or processes data stored in memory **104** and/or other computer-readable media accessible to controller **103**.

Memory **104** may be housed within enclosure **101**, may be communicatively coupled to controller **103**, and includes any system, device, or apparatus configured to retain program instructions and/or data for a period of time (e.g., computer-readable media). Memory **104** may include random access memory (RAM), electrically erasable programmable read-only memory (EEPROM), a Personal Computer Memory Card International Association (PCMCIA) card, flash memory, magnetic storage, opto-magnetic storage, or any suitable selection and/or array of volatile or non-volatile memory that retains data after power to mobile device **102** is turned off.

4

User interface **105** may be housed at least partially within enclosure **101**, may be communicatively coupled to controller **103**, and comprises any instrumentality or aggregation of instrumentalities by which a user may interact with user mobile device **102**. For example, user interface **105** may permit a user to input data and/or instructions into user mobile device **102** (e.g., via a keypad and/or touch screen), and/or otherwise manipulate mobile device **102** and its associated components. User interface **105** may also permit mobile device **102** to communicate data to a user, e.g., by way of a display device.

Capacitive microphone **106** may be housed at least partially within enclosure **101**, may be communicatively coupled to controller **103**, and comprises any system, device, or apparatus configured to convert sound incident at microphone **106** to an electrical signal that may be processed by controller **103**, wherein such sound is converted to an electrical signal using a diaphragm or membrane having an electrical capacitance that varies as based on sonic vibrations received at the diaphragm or membrane. Capacitive microphone **106** may include an electrostatic microphone, a condenser microphone, an electret microphone, a microelectromechanical systems (MEMs) microphone, or any other suitable capacitive microphone.

Radio transmitter/receiver **108** may be housed within enclosure **101**, may be communicatively coupled to controller **103**, and includes any system, device, or apparatus configured to, with the aid of an antenna, generate and transmit radio-frequency signals as well as receive radio-frequency signals and convert the information carried by such received signals into a form usable by controller **103**. Radio transmitter/receiver **108** may be configured to transmit and/or receive various types of radio-frequency signals, including without limitation, cellular communications (e.g., 2G, 3G, 4G, LTE, etc.), short-range wireless communications (e.g., BLUETOOTH), commercial radio signals, television signals, satellite radio signals (e.g., GPS), Wireless Fidelity, etc.

A speaker **110** may be housed at least partially within enclosure **101** or may be external to enclosure **101**, may be communicatively coupled to controller **103**, and may comprise any system, device, or apparatus configured to produce sound in response to electrical audio signal input. In some embodiments, a speaker may comprise a dynamic loudspeaker, which employs a lightweight diaphragm mechanically coupled to a rigid frame via a flexible suspension that constrains a voice coil to move axially through a cylindrical magnetic gap. When an electrical signal is applied to the voice coil, a magnetic field is created by the electric current in the voice coil, making it a variable electromagnet. The coil and the driver's magnetic system interact, generating a mechanical force that causes the coil (and thus, the attached cone) to move back and forth, thereby reproducing sound under the control of the applied electrical signal coming from the amplifier.

In embodiments in which mobile device **102** includes a plurality of speakers **110**, such speakers **110** may serve different functions. For example, in some embodiments, a first speaker **110** may play ringtones and/or other alerts while a second speaker **110** may play voice data (e.g., voice data received by radio transmitter/receiver **108** from another party to a phone call between such party and a user of mobile device **102**). As another example, in some embodiments, a first speaker **110** may play voice data in a "speakerphone" mode of mobile device **102** while a second speaker **110** may place voice data when the speakerphone mode is disabled.

Although specific example components are depicted above in FIG. 1 as being integral to mobile device **102** (e.g., con-

5

troller 103, memory 104, user interface 105, microphone 106, radio transmitter/receiver 108, speakers(s) 110), a mobile device 102 in accordance with this disclosure may comprise one or more components not specifically enumerated above.

In accordance with embodiments of the present disclosure, one or more of speakers 110 may also be employed as a microphone. To illustrate, sound incident on a cone or other sound producing component of a speaker 110 may cause motion in such cone, thus causing motion of the voice coil of such speaker 110, which induces a voltage on the voice coil which may be sensed and transmitted to controller 103 and/or other circuitry for processing, effectively operating as a microphone. Sound detected by a speaker 110 used as a microphone may be used for many purposes, as described below.

For example, in some embodiments a speaker 110 may be used as a microphone to sense voice commands and/or other audio stimulus for “waking up” mobile device 102 from a low-power state and transitioning it to a higher-power state. In such embodiments, when mobile device 102 is in a low-power state, a speaker 110 may communicate electronic signals to controller 103 for processing. Controller 103 may process such signals and determine if such signals correspond to a voice command and/or other stimulus for transitioning mobile device 102 to a higher-power state. If controller 103 determines that such signals correspond to a voice command and/or other stimulus for transitioning mobile device 102 to a higher-power state, controller 103 may activate one or more components of mobile device 102 that may have been deactivated in the low-power state (e.g., capacitive microphone 106, user interface 105).

In some instances, a speaker 110 may be used as a microphone for sound pressure levels or volumes above a certain level, such as the recording of a live concert, for example. In such higher sound levels, a speaker 110 may have a more reliable signal response to sound as compared with capacitive microphone 106. When using a speaker 110 as a microphone, controller 103 and/or other components of mobile device 102 may perform frequency equalization, as the frequency response of a speaker 110 employed as a microphone may be different than capacitive microphone 106. Such frequency equalization may be accomplished using filters (e.g., a filter bank) as is known in the art. In particular embodiments, such filtering and frequency equalization may be adaptive, with an adaptive filtering algorithm performed by controller 103 during periods of time in which both capacitive microphone 106 is active (but not overloaded by the incident volume of sound) and a speaker 110 is used as a microphone. Once the frequency response is equalized, controller 103 may smoothly transition between the signals received from capacitive microphone 106 and speaker 110 by cross-fading between the two.

In these and other embodiments, controller 103 may process signals received from capacitive microphone 106 and one or more speakers 110 employed as microphones in order to perform beamforming or spatial filtering, which is a signal processing technique for directional signal reception. Controller 103 may perform beamforming by combining elements in a phased array in such a way that signals at particular angles experience constructive interference while others experience destructive interference. Beamforming may be in order to achieve spatial selectivity of sounds incident at mobile device 102.

In these and other embodiments, a speaker 110 may be used as a microphone in those instances in which it is not otherwise being employed to emit sound. For example, when mobile device 102 is in a low-power state, a speaker 110 may

6

not emit sound and thus may be employed as a microphone (e.g., to assist in waking mobile device 102 from the low-power state in response to voice activation commands, as described above). As another example, when mobile device 102 is in a speakerphone mode, a speaker 110 typically used for playing voice data to a user when mobile device 102 is not in a speakerphone mode (e.g., a speaker 110 the user typically holds to his or her ear during a telephonic conversation) may be deactivated from emitting sound and in such instance may be employed as a microphone.

However, in other embodiments, a speaker 110 may be used simultaneously as a speaker and a microphone, such that a speaker 110 may simultaneously emit sound while capturing sound. In such embodiments, a cone and voice coil of a speaker 110 may vibrate both in response to a voltage signal applied to the voice coil and other sound incident upon speaker 110. Controller 103 may determine a voltage present on the voice coil, which will include the sum of two voltages: a voltage transmitted (e.g., by controller 103) for generating sound from the speaker 110 and a voltage induced by external sound incident on the speaker 110. By performing signal processing, controller 103 may subtract the voltage attributable to generating sound from the total voltage present on the voice coil, with the remaining voltage being attributable to the external sound incident on the speaker 110.

In these and other embodiments, a speaker 110 may be used as a microphone in order to extend a bass response of mobile device 102 beyond that of capacitive microphone 106. Typical capacitive microphones have limited frequency response, especially at low frequencies. However, when used as a microphone, a speaker 110 may have a better low-frequency response as compared to capacitive microphones typically employed in mobile devices. Thus, controller 103 may filter and sum signals from capacitive microphone 106 and one or more speakers 110 to provide a greater frequency response for reception of sound than might be available from capacitive microphone 106 alone.

In these and other embodiments, mobile device 102 may include at least two speakers 110 which may be selectively used to transmit sound or as a microphone. In such embodiments, each speaker 110 may be optimized for performance at a particular volume level range and/or frequency range, and controller 103 may select which speaker(s) 110 to use for transmission of sound and which speaker(s) 110 to use for reception of sound based on detected volume level and/or frequency range.

FIG. 2 illustrates a flow chart of an example method 200 for using a speaker 110 as a microphone in order to detect audio stimulus for waking mobile device 102 from a low-power state, in accordance with embodiments of the present disclosure. According to one embodiment, method 200 begins at step 202. As noted above, teachings of the present disclosure are implemented in a variety of configurations of mobile device 102. As such, the preferred initialization point for method 200 and the order of the steps comprising method 200 may depend on the implementation chosen.

At step 202, a speaker 110 may be disabled from generating sound responsive to mobile device 102 entering a low-power state. At step 204, the speaker 110 may, responsive to sound incident upon speaker 110, transmit a voltage signal induced in the speaker 110 by the incident sound to controller 103.

At step 206, controller 103 may process the voltage signal and determine if the voltage signal corresponds to a stimulus (e.g., voice command) for transitioning mobile device 102 from a low-power state to a higher-power state. If the voltage signal corresponds to a stimulus for transitioning mobile

7

device **102** from a low-power state to a higher-power state, method **200** may proceed to step **208**. Otherwise, method **200** may proceed again to step **204**.

At step **208**, responsive to determining that the voltage signal corresponds to a stimulus for transitioning mobile device **102** from a low-power state to a higher-power state, controller **103** may activate the higher-power state by activating one or more components of mobile device **102** that may have been deactivated in the low-power state (e.g., capacitive microphone **106**, user interface **105**). After completion of step **208**, method **200** may end.

Although FIG. 2 discloses a particular number of steps to be taken with respect to method **200**, method **200** may be executed with greater or fewer steps than those depicted in FIG. 2. In addition, although FIG. 2 discloses a certain order of steps to be taken with respect to method **200**, the steps comprising method **200** may be completed in any suitable order.

Method **200** may be implemented using mobile device **102** or any other system operable to implement method **200**. In certain embodiments, method **200** may be implemented partially or fully in software and/or firmware embodied in computer-readable media (e.g., memory **104**) and executable by a controller (e.g., controller **103**).

FIG. 3 illustrates a flow chart of an example method **300** for using a speaker **110** as a microphone at higher volume levels not suitable for reception by capacitive microphone **106**, in accordance with embodiments of the present disclosure. According to one embodiment, method **300** begins at step **302**. As noted above, teachings of the present disclosure are implemented in a variety of configurations of mobile device **102**. As such, the preferred initialization point for method **300** and the order of the steps comprising method **300** may depend on the implementation chosen.

At step **302**, a speaker **110** may, responsive to sound incident upon speaker **110**, transmit a first voltage signal induced in the speaker **110** by incident sound to controller **103**. At step **304**, a capacitive microphone **106** may, responsive to sound incident upon capacitive microphone **106**, transmit a second voltage signal induced in capacitive microphone **106** by incident sound to controller **103**.

At step **306**, controller **103** may perform frequency equalization on the first voltage signal and the second voltage signal in order to account for differences in the frequency responses for sound received at the speaker **110** and capacitive microphone **106**. Such frequency equalization may be accomplished using filters (e.g., a filter bank) as is known in the art. In particular embodiments, such filtering and frequency equalization may be adaptive, with an adaptive filtering algorithm performed by controller **103** during periods of time in which both capacitive microphone **106** is active (but not overloaded by the incident volume of sound) and a speaker **110** is used as a microphone. Once the frequency response is equalized, controller **103** may smoothly transition between the signals received from capacitive microphone **106** and speaker **110** by cross-fading between the two. After completion of step **306**, method **300** may end.

Although FIG. 3 discloses a particular number of steps to be taken with respect to method **300**, method **300** may be executed with greater or fewer steps than those depicted in FIG. 3. In addition, although FIG. 3 discloses a certain order of steps to be taken with respect to method **300**, the steps comprising method **300** may be completed in any suitable order.

Method **300** may be implemented using mobile device **102** or any other system operable to implement method **300**. In certain embodiments, method **300** may be implemented par-

8

tially or fully in software and/or firmware embodied in computer-readable media (e.g., memory **104**) and executable by a controller (e.g., controller **103**).

Methods similar to that shown in FIG. 3 may also be used for employing a speaker **110** as a microphone at frequency ranges (e.g., low-frequency ranges) not suitable for reception by capacitive microphone **106**, as described above.

FIG. 4 illustrates a flow chart of an example method **400** for simultaneously using a speaker **110** as a speaker and a microphone such that the speaker **110** may simultaneously emit sound while capturing sound, in accordance with embodiments of the present disclosure. According to one embodiment, method **400** begins at step **402**. As noted above, teachings of the present disclosure are implemented in a variety of configurations of mobile device **102**. As such, the preferred initialization point for method **400** and the order of the steps comprising method **400** may depend on the implementation chosen.

At step **402**, controller **103** may determine a total voltage present on a voice coil of a speaker **110**. Such voltage may include the sum of two individual voltages: a first voltage transmitted (e.g., by controller **103**) for generating sound from the speaker **110** and a second voltage induced by external sound incident on the speaker **110**.

At step **404**, controller **103** may subtract the first voltage (attributable to generating sound) from the total voltage present on the voice coil, with the remaining voltage being approximately equal to the second voltage induced by external sound incident on the speaker **110**.

At step **406**, controller **103** may process the second voltage in order to perform any suitable functionality responsive to such second voltage. After completion of step **406**, method **400** may end.

Although FIG. 4 discloses a particular number of steps to be taken with respect to method **400**, method **400** may be executed with greater or fewer steps than those depicted in FIG. 4. In addition, although FIG. 4 discloses a certain order of steps to be taken with respect to method **400**, the steps comprising method **400** may be completed in any suitable order.

Method **400** may be implemented using mobile device **102** or any other system operable to implement method **400**. In certain embodiments, method **400** may be implemented partially or fully in software and/or firmware embodied in computer-readable media (e.g., memory **104**) and executable by a controller (e.g., controller **103**).

FIG. 5 illustrates a flow chart of an example method **500** for selectively enabling speakers **110** for transmitting sound or receiving sound, in accordance with embodiments of the present disclosure. According to one embodiment, method **500** begins at step **502**. As noted above, teachings of the present disclosure are implemented in a variety of configurations of mobile device **102**. As such, the preferred initialization point for method **500** and the order of the steps comprising method **500** may depend on the implementation chosen.

At step **502**, one or more speakers **110** may, responsive to sound incident upon speakers **110**, transmit a voltage signal induced in the speakers **110** by incident sound to controller **103**. At step **504**, controller **103** may process the voltage signal to determine a volume level and/or frequency of the incident sound.

At step **506**, controller **103** may enable one or more speakers **110** to transmit sound (e.g., be used as a speaker) based on the determined volume level and/or frequency of the incident sound. At step **508**, controller **103** may enable one or more speakers **110** to receive sound (e.g., be used as a microphone)

based on the determined volume level and/or frequency of the incident sound. After completion of step 508, method 500 may end.

Although FIG. 5 discloses a particular number of steps to be taken with respect to method 500, method 500 may be executed with greater or fewer steps than those depicted in FIG. 5. In addition, although FIG. 5 discloses a certain order of steps to be taken with respect to method 500, the steps comprising method 500 may be completed in any suitable order.

Method 500 may be implemented using mobile device 102 or any other system operable to implement method 500. In certain embodiments, method 500 may be implemented partially or fully in software and/or firmware embodied in computer-readable media (e.g., memory 104) and executable by a controller (e.g., controller 103).

This disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Similarly, where appropriate, the appended claims encompass all changes, substitutions, variations, alterations, and modifications to the example embodiments herein that a person having ordinary skill in the art would comprehend. Moreover, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, or component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are construed as being without limitation to such specifically recited examples and conditions. Although embodiments of the present inventions have been described in detail, it should be understood that various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the disclosure.

What is claimed is:

1. A device comprising:

a speaker for generating sound;

a capacitive microphone configured to generate a second signal induced by sound incident on the capacitive microphone; and

a controller, communicatively coupled to the speaker, and configured to:

receive a first signal from the speaker, the first signal induced at least in part by sound incident on the speaker other than sound generated by the speaker; receive the second signal from the capacitive microphone, the second signal induced by sound incident on the capacitive microphone; and

process at least one of the first signal and the second signal to determine at least one characteristic of sound incident upon at least one of the speaker and the capacitive microphone, wherein the at least one characteristic comprises a frequency; and

select one of the capacitive microphone and the speaker as a signal source for incident sound based on the characteristic.

2. The device of claim 1, wherein the first signal is a voltage signal.

3. The device of claim 1, wherein the controller is further configured to:

operate the speaker in a first mode wherein the controller communicates an output signal to the speaker for generating sound; and

operate the speaker in a second mode wherein the controller deactivates the speaker from emitting sound and receives the first signal induced by sound incident on the speaker other than sound generated by the speaker and processes the signal.

4. The device of claim 1, wherein the controller is further configured to transition the device from a low-power state to a high-power state responsive to a determination that the first signal induced by sound incident on the speaker corresponds to stimulus for transitioning the device from a low-power state to a high-power state.

5. The device of claim 1, wherein the controller is further configured to perform frequency equalization on the first signal and the second signal in order to account for differences in the frequency responses to sound incident upon the speaker and the capacitive microphone, wherein performing frequency equalization on the first signal and the second signal comprises applying adaptive filtering during periods of time in which both the capacitive microphone is communicating the second signal to the controller and the speaker is communicating the first signal to the controller.

6. The device of claim 1, wherein the at least one characteristic comprises a sound level.

7. The device of claim 1, wherein the controller is configured to:

determine a magnitude of the first signal; and

subtract a magnitude of a second signal from the magnitude of the first signal, the second signal communicated by the controller to the speaker for generating sound at the speaker, such that a difference between the magnitude of the first signal and the magnitude of the second signal is approximately equal to a portion of the first signal attributable to sound incident on the speaker other than sound generated by the speaker.

8. The device of claim 1, wherein the controller is further configured to, based on sound incident at the speaker and sound incident on the capacitive microphone, perform beamforming to determine spatial selectivity of sounds incident on the device.

9. The device of claim 1, wherein the speaker is a dynamic speaker.

10. A method comprising:

generating, by a speaker, a first signal, the first signal induced at least in part by sound incident on the speaker other than sound generated by the speaker;

receiving a second signal from a capacitive microphone, the second signal induced by sound incident on the capacitive microphone; and

processing at least one of the first signal and the second signal to determine at least one characteristic of sound incident upon at least one of the speaker and the capacitive microphone, wherein the at least one characteristic comprises a frequency; and

selecting one of the capacitive microphone and the speaker as a signal source for incident sound based on the characteristic.

11. The method of claim 10, wherein the first signal is a voltage signal.

11

12. The method of claim 10, further comprising:
operating the speaker in a first mode wherein a controller
within the enclosure communicates an output signal to
the speaker for generating sound; and
operating the speaker in a second mode wherein the con- 5
troller deactivates the speaker from emitting sound and
receives the first signal induced by sound incident on the
speaker other than sound generated by the speaker and
processes the first signal.
13. The method of claim 10, further comprising transition- 10
ing a device comprising the speaker from a low-power state to
a high-power state responsive to a determination that the first
signal induced by sound incident on the speaker corresponds
to stimulus for transitioning the device from a low-power
state to a high-power state.
14. The method of claim 10, further comprising perform- 15
ing frequency equalization on the first signal and the second
signal in order to account for differences in the frequency
responses to sound incident upon the speaker and the capaci-
tive microphone, wherein performing frequency equalization 20
on the first signal and the second signal comprises applying
adaptive filtering during periods of time in which both the
capacitive microphone is communicating the second signal to
the controller and the speaker is communicating the first
signal to the controller.
15. The method of claim 10, wherein the at least one 25
characteristic comprises a sound level.
16. The method of claim 10, wherein processing the first
signal comprises:
determining a magnitude of the first signal; and 30
subtracting a magnitude of a second signal from the mag-
nitude of the first signal, the second signal communi-
cated to the speaker for generating sound at the speaker,
such that a difference between the magnitude of the first 35
signal and the magnitude of the second signal is approxi-
mately equal to a portion of the first signal attributable to
sound incident on the speaker other than sound gener-
ated by the speaker.
17. The method of claim 10, further comprising:
based on sound incident at the speaker and sound incident 40
on the capacitive microphone, performing beamforming
to determine spatial selectivity of sounds incident on the
mobile device.
18. The method of claim 10, wherein the speaker is a 45
dynamic speaker.
19. A device comprising:
a first speaker for generating sound;
a second speaker for generating sound; and

12

- a controller, communicatively coupled to the first speaker
and the second speaker, and configured to:
receive a first signal from the first speaker, the first signal
induced at least in part by sound incident on the first
speaker other than sound generated by the first
speaker;
receive a second signal from the first speaker, the second
signal induced at least in part by sound incident on the
second speaker other than sound generated by the
second speaker;
process at least one of the first signal and the second
signal to determine at least one characteristic of sound
incident on at least one of the first speaker and the
second speaker;
select one of the first speaker and the second speaker as 15
a signal source for incident sound based on the at least
one characteristic; and
select the other one of the first speaker and the second
speaker to generate sound based on the at least one
characteristic.
20. The device of claim 19, wherein the at least one char-
acteristic comprises at least one of a volume level of sound
incident on the device and a frequency of sound incident on
the device.
21. A method comprising:
generating, by a first speaker, a first signal, the first signal
induced at least in part by sound incident on the first
speaker other than sound generated by the first speaker;
generating, by a second speaker, a second signal, the sec-
ond signal induced at least in part by sound incident on
the second speaker other than sound generated by the
second speaker;
processing at least one of the first signal and the second
signal to determine at least one characteristic of sound
incident on at least one of the first speaker and the second
speaker;
selecting one of the first speaker and the second speaker as
a signal source for incident sound based on the at least
one characteristic; and
selecting the other one of the first speaker and the second
speaker to generate sound based on the at least one
characteristic.
22. The method of claim 21, wherein the at least one
characteristic comprises at least one of a volume level of
sound incident on at least one of the first speaker and the
second speaker and a frequency of sound incident on at least
one of the first speaker and the second speaker.

* * * * *